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Author: José Pablo Paredes-Sánchez Antonio José Gutiérrez-Trashorras Jorge Xiberta-Bernat

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HIGHLIGHTS

Urban forestry and urban greening are potential energy suppliers.

Urban forests will contribute to the bioenergy development in Asturias (Spain).

Wood from urban forests can replace fossil fuels in thermal and power applications.

A pellet plant uses 51 kt/year of wood residues from the studied area.

Wood Residue to Energy from Forests in the Central Metropolitan Area of Asturias (NW Spain)

José Pablo Paredes-Sánchez[a,*], Antonio José Gutiérrez-Trashorras[b] and Jorge Xiberta-Bernat[c]

[a,*] Corresponding author: José Pablo Paredes-Sánchez, Department of Energy, University of Oviedo, C/Independencia 13, 33004 Oviedo, Spain. Tfno: +34 985104305. Email: paredespablo@uniovi.es

[b] Department of Energy, University of Oviedo, C/Independencia 13, 33004 Oviedo, Spain. Email: gutierrezantonio@uniovi.es

[c] Department of Energy, University of Oviedo, C/Independencia 13, 33004 Oviedo, Spain. Email: jxiberta@uniovi.es

Abstract

Nowadays, high-density population in urban areas coexist with rural industrial zones, such is the case of the Central Metropolitan Area (CMA) of the Principality of Asturias (NW Spain) where 78% of the population of the region lives, and where 14% of the Asturian forests are located. This situation generates significant amounts of forest residues from management activities. The urban forests of the CMA generate large amounts of biomass residues, consisting primarily of branches from cleaning, thinning and felling operations. The available residues are suitable as biomass feedstock considering techno-economical and environmental constraints. The method used to choose the most suitable location for a pellet plant to process available residues is based on GIS software. This study has assessed the available biomass feedstock and the management implications to maximize the availability of forest residues for bioenergy. The calculated potential amount of wood residue is 92.7 dry kt year^{-1}, equivalent to 920.1 TJ year^{-1}. The municipality of Corvera has been proposed as the most suitable CMA location for a pellet plant. The plant could reach an annual pellet production capacity of 51 kt, equivalent to 32 MW$_{th}$ of fuel output.

Keywords

Biofuel; Biomass; BIORAISE methodology; Pellet plant.

Introduction

Bioenergy produced in Europe is projected to cover about 10.5% of gross energy consumption by 2020, approximately 17% of which would come from forests (Sjølie and Solberg, 2011). The use of natural resources represents one of the greatest challenges in the European Union (EU). The EU policy supports an integrated approach to regional development, considering the dimensions of sustainable development and efficient exploitation of forests. More than two thirds of the population of Europe lives in urban areas, where forests of metropolitan areas produce various types of energy benefits and costs (Soares et al., 2011). Sustainable policies have become an integral part of national and regional ones. However, integration between waste management and energy production is difficult (Paredes-Sánchez, 2010).

Planning, creating and managing urban and peri-urban forests impose new demands on forest managers, particularly when it comes to engaging local communities, who may be affected by or expecting to benefit from forest management . Wood waste is one of the major biodegradable components in municipal solid waste (Barlaz, 2006). Proper waste management is necessary for health purposes, for protection the environment and for sustainable development. Many studies have been carried out to assess the energy potential from wood residue management (Bergeron, 2014).Urban and peri-urban forests generate significant amounts of wood waste as an energy source (Timilsina et al., 2014). Forest residue management could contribute to the conservation of natural resources and production of solid biofuels (e.g. pellets, briquettes and wood chips) (Rosillo-Calle et al., 2007; Paredes-Sánchez and Xiberta-Bernat, 2010).

Pellets in particular, are widely used for heating in the residential sector and in the combustion processes in coal power plants. Liquid fuels (diesel) and gas fuels (liquefied petroleum gas (LPG)) may be offset by pellets in the European energy market. The energy cost of diesel and LPG is more than 40% higher than wood pellet. The wood pellet energy cost is estimated at 0.01 EUR MJ^{-1} (IDAE, 2013).

Solid fossil fuel (coal) could be partially replaced by cofiring with wood pellet in power plants. The costs of biomass and individual characteristics of the power plant are still major barriers (Saidur et al., 2011).

The study on distribution of cost in pellet production reveals that the cost of raw material is the highest, close to 40% of the total (Monteiro et al., 2012). In this sense, in the European energy sector the profitable feedstock cost of woody biomass at pellet plant gate in operation varies between 83 and 110 EUR dry t^{-1} (Trømborg et al., 2013). The economic sustainability of European pellet plants depends on their markets as well as on the international pellet prices. The pellet price without Value Added Tax (VAT) is 134 EUR t^{-1} in bulk and 179 EUR t^{-1} in bags (IDAE, 2013).

Asturias is a region in Northwest Spain with significant industrial activity, especially in the cement and energy sectors. Its Central Metropolitan Area (CMA) has 1,907 km^2 or 18% of the total territory, where 78% of its population live (Paredes-Sánchez et al., 2014; SADEI, 2014). The forests in the CMA, covering 14% of the forest area of the region (4,581 km^2), consist of coniferous and broadleaved species. The natural vegetation is made up of oak, chestnut and beech trees. Other kinds of trees have also adapted well, such as pine and eucalyptus trees . The unwieldy topography of this area makes it difficult to carry out proper municipal waste management of the wood residue generated in these forests. This problem is accentuated by a lack of suitable machinery to carry out the tasks involved in sustainable forest management such as cleaning, thinning and felling operations.

Urban forests range from parks to peri-urban forests under the influence of municipal territory (Seeland et al., 2002). The urban and peri-urban forests aim to reconcile sustainable and recreational use, economic efficiency and social acceptability in the CMA.

The useful residues generated as a consequence of forest management operations are mainly remains of trees and vegetation. Forest residues have no specific or clear applications in the region.

The Regional Administration of the Principality of Asturias manages the conservation and improvement of forests, provides subsidies and establishes consortiums with the municipalities of the CMA, conditioned by the general budget assigned each year. So far, no studies have been carried out on the municipal waste management of the forests in the CMA or of those that could be recovered for energy purposes considering technical and environmental constraints (Paredes-Sánchez, 2010).

Techno-economical constrains derive from ground conditions to access to raw material and environmental constraints come from ground nature.

The woody residues are currently left and stacked up on the ground or, in less than one third of the cases, are stored in a landfill managed by COGERSA (Consortium for Solid Residue Management in Asturias) (Rodríguez-Iglesias et al., 2003; Paredes-Sánchez, 2010), which are wasted rather than used for bioenergy. These woody residues are suitable for bioenergy production, avoiding also forest fires and the spread of plagues. In this regard, the Regional Administration is working to establish an appropriate legal framework to ensure sustainable waste management of the forests. The aim of this work is to evaluate the available biomass for bioenergy and the management implications for urban forest managers, to maximize the availability of forest residues for bioenergy in the CMA.

Material and methods

Many studies which have been carried out to determine woody residue in a given territory using the Geographic Information Systems (GIS) (Nord-Larsen and Talbot, 2004; Kinoshita et al., 2009).

In this study, the BIORAISE GIS software from the Research Centre for Energy, Environment and Technology (CIEMAT) is used to evaluate forest biomass in each of the municipalities in the CMA. The BIORAISE GIS software calculates the residue mass in a geographic area, its energy content and the costs incurred in collection and transportation.

The residues in each municipality are calculated by taking the collection area within the municipality borders into consideration. The centre of each municipality is taken as a collection point. Regarding forest biomass, the model is based on the European cartography of land uses Corine Land Cover (CLC) and Mean Annual Productivity Values (MAPV) of residual biomass for each forest type from the BIORAISE GIS database.

Wood residues consist of branches and tops (including leaves) obtained from cleaning, thinning and felling operations. The evaluated residues are from specie categories (conifers, broadleaves and mixtures of conifers and broadleaves). Hereinafter the latter ones will be referred to as mixtures. The nutritional impact of residues collection is influenced by the degree of branches extraction from the collection area. More productive soils can tolerate a higher degree of biomass extraction. The collection of forest residues on sites with shallow soils could increase erosion risk (Verkerk et al., 2011). Part of the mass of residues is lost before reaching the collection point, due to loss or damage of biomass during harvesting.

Collection efficiency depends on the harvesting method (Peltola et al., 2011). Collection efficiency is the relationship between the mass of available residue and the mass of total residue in the collection area.

The moisture content is variable, as it depends on the specie categories, age of trees at collection and on the time that elapses between collection and use (Frombo et al., 2009). The collected residues are evaluated on an oven dry mass basis (dry t) (BIORAISE, 2014).

The total residue mass (M) in the collection area consists of wood residues from forest management operations which were evaluated in terms of dry tonne (dry t) according to Equation 1.

$$M = M_1 + M_2 + M_3 \qquad (1)$$

where:

M: mass of total residue (dry t year^{-1}).

M_1: mass of total broadleaves residue (dry t year^{-1}).

M_2: mass of total conifers residue (dry t year^{-1}).

M_3: mass of total mixtures residue (dry t year^{-1}).

The available mass and energy are calculated by the analysis model of BIORASE GIS software, which considers techno-economical and environmental constraints. Techno-economical factors derive from the harvesting methods based on ground conditions to access to raw material and from the different forest operations for specie categories in the collection area. Environmental constraints can also limit the quantities of harvestable biomass; such limitations come from the slope, the erosion risk and the needs of organic carbon content in topsoil (BIORAISE, 2014).

The database utilized for the mentioned constraints by BIORAISE GIS software were gathered from the following sources:

- Slope was obtained from the World SRTM90 digital elevation data.
- Erosion risk was taken from the PSERA Map (Pan-European Soil Erosion Risk Assessment).
- Organic carbon content in soils was obtained from The Map of Organic Carbon in topsoils in Europe.

The available residue mass (m) is the accessible mass to be energetically exploited under techno-economical and environmental constraints, obtained from existing and recoverable one (M) . In these conditions, the available residues mass may be completely transformed into pellets. It is calculated according to Equation 2.

$$m = m_1 + m_2 + m_3 \qquad (2)$$

where:

m: mass of available residue (dry t year^{-1}).

m_1: mass of available broadleaves residue (dry t year^{-1}).

m_2: mass of available conifers residue (dry t year^{-1}).

m_3: mass of available mixtures residue (dry t year^{-1}).

The average energy content, measured in Lower Heating Value (LHV) from the moisture free residue has been evaluated at 17.7, 19.0 and 18.3 GJ dry t^{-1} in broadleaves, conifers and mixtures, respectively (BIORAISE, 2014). The energy from the available residue (*E*) is the result of multiplying the mass from the available residue by its energy content (Paredes-Sánchez et al., 2014). Equation 3.

$$E = m_1 \cdot LHV_1 + m_2 \cdot LHV_2 + m_3 \cdot LHV_3 \qquad (3)$$

where:

E: energy from available residue (GJ year^{-1}).

LHV_1: broadleaves energy content (GJ dry t^{-1}).

LHV_2: conifers energy content (GJ dry t^{-1}).
LHV_3: mixtures energy content (GJ dry t^{-1}).

BIORAISE GIS software takes into account the average moisture content of the residues as the time collection when calculating the collection and transportations costs.

The total cost (*TC*) of the available residue is the sum of the average collection (*Cc*) and transportation (*Ct*) costs, Equation 4.

$$TC = Cc + Ct \tag{4}$$

TC: total cost (EUR dry t^{-1}).
Cc: average collection cost of available residue (EUR dry t^{-1}).
Ct: average transportation cost of available residue (EUR dry t^{-1}).

The average collection cost (*Cc*) is the cost of the available residue in dry t. Collection cost of available residue includes harvesting, conditioning and packaging, Equation 5.

$$Cc = (m_1 \cdot Cc_1 + m_2 \cdot Cc_2 + m_3 \cdot Cc_3)/m \tag{5}$$

where:
Cc: average collection cost of available residue (EUR dry t^{-1}).
Cc_1: collection cost of broadleaves (EUR dry t^{-1}).
Cc_2: collection cost of conifers (EUR dry t^{-1}).
Cc_3: collection cost of mixtures (EUR dry t^{-1}).

The average transportation cost (*Ct*) is the cost per dry t of the available residue transported to the collection point. Transportation cost includes driver, vehicle and fuel; for the latter, a diesel average price of 1.45 EUR l^{-1} is assumed, Equation 6.

$$Ct = (m_1 \cdot Ct_1 + m_2 \cdot Ct_2 + m_3 \cdot Ct_3)/m \tag{6}$$

where:
Ct: average transportation cost of available residue (EUR dry t^{-1}).
Ct_1: transportation cost of broadleaves (EUR dry t^{-1}).
Ct_2: transportation cost of conifers (EUR dry t^{-1}).
Ct_3: transportation cost of mixtures (EUR dry t^{-1}).

Results and discussion

Technical constraints assume an average collection efficiency of about 70% in the collection area. Areas with slopes steeper than 60% have been considered unavailable as they are virtually inaccessible for the forest management. In all situations, 20% of biomass has been considered unreachable due to the difficulties of machinery to collect all the material. Therefore, specific harvesting method should be evaluated in extremely steep slopes where the environmental consequences of biomass removal should be carefully evaluated. As pointed out earlier, the reduction of forest fire risk is extremely beneficial when the biomass produced in forest operations is removed. For this reason, no special limitations on biomass availability have been considered in protected areas of urban forests (BIORAISE, 2014).

Table 1 shows the mass of the total residue, and the mass, energy and costs of the available residue.

(Table 1 here)

Table 1. Mass, energy and costs of residues in the municipalities of the CMA.

Table 1 shows that the municipality of Corvera has the lowest total cost as well as having a significant number of potential end users in its vicinity, such as the urban and industrial centers of Avilés and Gijón (Fig. 1), a cement plant and a coal-fired power station. It also has an excellent transport network whether at regional, national or international levels. The average collection efficiency in the municipalities of the CMA is 55.9% where the collection efficiency in Corvera is 73.2%.

Therefore, we conclude that Corvera would be the best place to locate a wood waste plant to produce pellets in the CMA. Within this municipality, Cancienes Industrial Estate has been selected as it is extremely well connected by road with the rest of the CMA. Fig. 1 shows the location of the mentioned pellet plant.

(Fig. 1 here)

Fig. 1. Collection area of the CMA residual forest biomass and pellet plant location (P) in Cancienes Industrial Estate (Corvera).

Adopting this collection point, the amount of residues and the total cost (collection and transportation) have been estimated for the defined area according to the distance between it and the border of the CMA (BIORAISE, 2014) (Fig. 1). Table 2 shows the values of mass, energy and costs of residues in this new considered management area, which includes some adjacent lands to the CMA.

(Table 2 here)

Table 2. Mass, energy and costs of residues with destination to the pellet plant.

The collection efficiency in the collection area with destination to the pellet plant is 56.9%. The total cost of the residues (collection cost plus transportation cost) supplied to the plant is 70.64 EUR dry t^{-1} (Table 2), slightly lower value than the average total cost of the CMA residues, 70.80 EUR dry t^{-1} (Table 1). Also, these figures are below 83 EUR dry t^{-1}, which is a viable cost of wood biomass feedstock at pellet plant gate in Europe (Trømborg et al., 2013).

Conclusions

The study carried out in the Central Metropolitan Area (CMA) of the Principality of Asturias (Spain) indicates that the total amount of wood residue is 92.7 dry kt year^{-1}. BIORAISE GIS software calculates the available mass of the residues by taking into account the forest management operations of the collection area under techno-economical and environmental constraints, with a collection efficiency over 55% in the CMA. The available residues amount to 51.8 dry kt year^{-1}, equivalent to 920.1 TJ year^{-1} (Table 1).

The municipality of Corvera (Fig. 1) is the municipality with the lowest total cost in the CMA (Table 1), therefore it has been chosen for a pellet plant location for these wastes. The plant should be built in Cancienes Industrial Estate (Corvera), because of its good transport connections and proximity to important potential end users of the residential and industrial sectors of this type of residues. The final quality of the pellet will depend on the process conditions and the demand of final consumers. The plant could have an annual production capacity of 51 kt (Table 2), equivalent to 32 MW_{th} as pellets for 8000 operating hours (Bergman, 2005; Nilsson et al., 2011). The use of these pellets in co-combustion with coal in the CMA power plants could produce 13 MW_e with an electricity efficiency of 0.40 (Moiseyev et al., 2013) and 7500 yearly operating hours (San Cristóbal, 2011).

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Figure captions

Fig. 1. Collection area of the CMA residual forest biomass and pellet plant location (P) in Cancienes Industrial Estate (Corvera).

Table captions

Table 1. Mass, energy and costs of residues in the municipalities of the CMA.

Table 2. Mass, energy and costs of residues with destination to the pellet plant.

Table 1. Mass, energy and costs of residues in the municipalities of the CMA.

Municipalities	*M* (dry t year^{-1})	m (dry t year^{-1})	*E* (GJ year^{-1})	*Cc*^{a} (EUR dry t^{-1})	*Ct*^{a} (EUR dry t^{-1})	*TC*^{a} (EUR dry t^{-1})
Aviles	512.15	372.54	6,754.53	58.26	4.58	62.84
Carreño	4,769.26	3,438.93	60,815.93	61.28	8.29	69.57
Castrillon	3,851.08	3,049.94	54,503.58	60.56	5.32	65.88
Corvera	2,804.2	2,053.13	37,029.26	53.40	4.98	58.37
Gijon	7,297.14	4,556.82	80,420.17	63.47	6.52	69.99
Gozón	3,879.58	2,135.29	37,909.84	60.31	5.27	65.58
Grado	11,157.97	5,329.97	94,492.63	65.31	15.00	80.31
Illas	1,987.93	1,356.12	24,612.67	62.64	11.05	73.70
Langreo	1,942.76	1,232.13	21,736.1	67.91	9.37	77.28
Las Regueras	3,100.36	1,190.41	21,048.99	62.03	10.50	72.53
Llanera	5,185.69	2,179.92	38,626.63	62.05	5.65	67.70
Mieres	4,688.73	2,222.06	39,656.44	70.17	9.39	79.56
Morcin	2,321.05	497.61	8,778.47	62.53	13.68	76.21
Noreña	128.23	97.85	1,726.16	60.92	7.46	68.38
Oviedo	8,555.17	3,627.91	64,175.43	63.18	7.73	70.91
Ribera de Arriba	1,006.64	428.73	7,563.34	63.42	8.71	72.13
Santo Adriano	852.76	94.3	1,663.7	66.94	15.01	81.95
Sariego	620.55	320.61	5,750.25	56.62	6.18	62.80
Siero	10,430.58	7,834.14	138,568.46	61.68	7.47	69.15
Villaviciosa	17,653.03	9,813.45	174,238.16	63.62	7.53	71.14
TOTAL	92,744.86	51,831.86	920,070.74	62.32	8.48	70.80

[a] Average value.

M, total residue mass; m, available residue mass; E, available residue energy.

Cc, collection cost; Ct, transportation cost; TC, total cost. Cc, Ct and TC are referred to available residues.

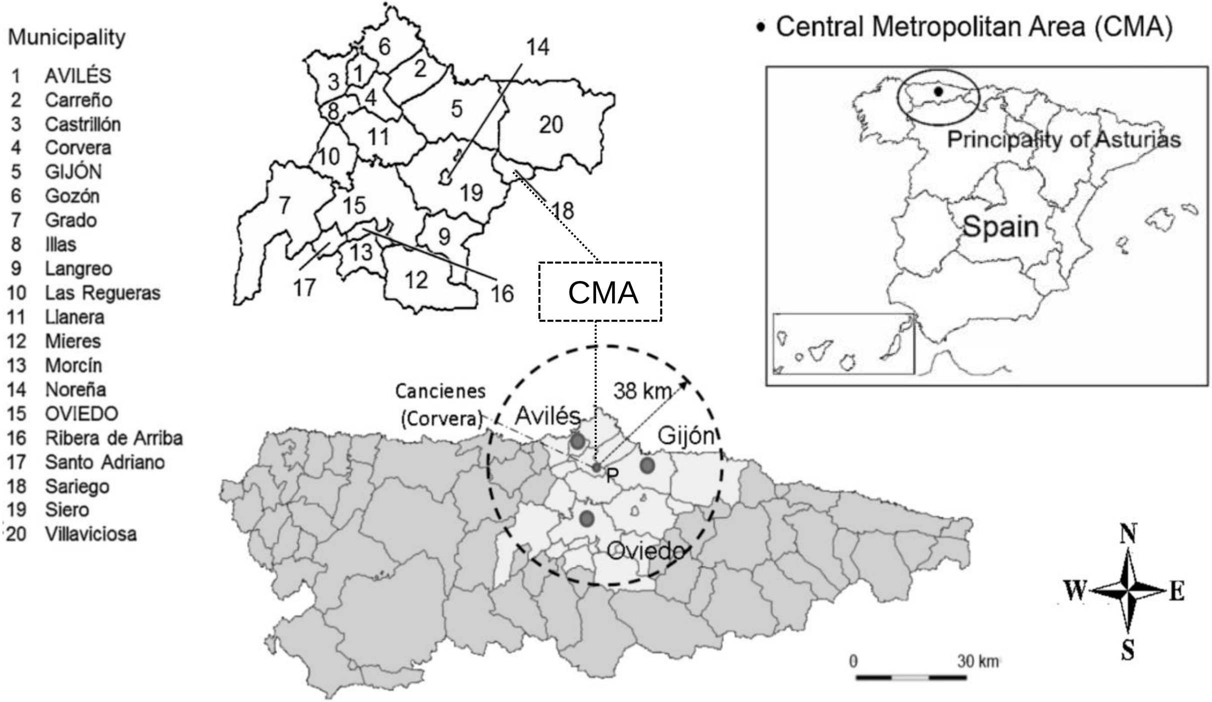
Table 2. Mass, energy and costs of residues with destination to the pellet plant.

Parameter	Unit	Result
Municipality		Corvera
Industrial estate		Cancienes
Collecting radius	km	38
m	dry t year^{-1}	50,950.10
E	GJ year^{-1}	906,459.34
Cc[a]	EUR dry t^{-1}	62.39
Ct[a]	EUR dry t^{-1}	8.25
TC[a]	EUR dry t^{-1}	70.64

[a] Average value.

M, total residue mass; m, available residue mass; E, available residue energy.

Cc, collection cost; *Ct*, transportation cost; *TC*, total cost. *Cc*, *Ct* and *TC* are referred to available residues.


Municipality
1 AVILÉS
2 Carreño
3 Castrillón
4 Corvera
5 GIJÓN
6 Gozón
7 Grado
8 Illas
9 Langreo
10 Las Regueras
11 Llanera
12 Mieres
13 Morcín
14 Noreña
15 OVIEDO
16 Ribera de Arriba
17 Santo Adriano
18 Sariego
19 Siero
20 Villaviciosa
• Central Metropolitan Area (CMA)
Principality of Asturias
Spain
CMA
Cancienes (Corvera)
Avilés
Gijón
Oviedo
P
38 km
0
30 km
N
S
W
E